PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

(Chapter II of the Patent Cooperation Treaty)

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference	FOR FURTHER ACTION	See Form PCT/IPEA/416
UNI001.007P/MAB		
International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/AU2004/001160	27 August 2004	27 August 2003

International Patent Classification (IPC) or national classification and IPC

Int. Cl.[7] G01B 9/02

Applicant

THE UNIVERSITY OF QUEENSLAND et al

1. This report is the international preliminary examination report, established by this International Preliminary Examining Authority under Article 35 and transmitted to the applicant according to Article 36.
2. This REPORT consists of a total of 3 sheets, including this cover sheet.
3. This report is also accompanied by ANNEXES, comprising:
   a. [X] *(sent to the applicant and to the International Bureau)* a total of 7 sheets, as follows:
      - [X] sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications authorized by this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions).
      - [ ] sheets which supersede earlier sheets, but which this Authority considers contain an amendment that goes beyond the disclosure in the international application as filed, as indicated in item 4 of Box No. I and the Supplemental Box.

   b. [ ] *(sent to the International Bureau only)* a total of (indicate type and number of electronic carrier(s)) , containing a sequence listing and/or table related thereto, in computer readable form only, as indicated in the Supplemental Box Relating to Sequence Listing (see Section 802 of the Administrative Instructions).
4. This report contains indications relating to the following items:
   - [X] Box No. I Basis of the report
   - [ ] Box No. II Priority
   - [ ] Box No. III Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   - [ ] Box No. IV Lack of unity of invention
   - [X] Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
   - [ ] Box No. VI Certain documents cited
   - [ ] Box No. VII Certain defects in the international application
   - [ ] Box No. VIII Certain observations on the international application

Date of submission of the demand	Date of completion of the report
9 December 2004	20 October 2005
Name and mailing address of the IPEA/AU	Authorized Officer
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INTERNATIONAL PRELIMINARY REPORT ON PATENTABILITY

International application No.
PCT/AU2004/001160

Box No. I Basis of the report

1. With regard to the **language**, this report is based on the international application in the language in which it was filed, unless otherwise indicated under this item.

☐ This report is based on translations from the original language into the following language , which is the language of a translation furnished for the purposes of:

☐ international search (under Rules 12.3 and 23.1 (b))

☐ publication of the international application (under Rule 12.4)

☐ international preliminary examination (under Rules 55.2 and/or 55.3)

2. With regard to the **elements** of the international application, this report is based on (*replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report*):

☐ the international application as originally filed/furnished

☒ the description:

pages **1, 5, 6, 8, 9** as originally filed/furnished
pages* **7** received by this Authority on **27 June 2005** with the letter of **27 June 2005**
pages* **2-4 a** received by this Authority on **12 October 2005** with the letter of **12 October 2005**

☒ the claims:

pages **11, 13** as originally filed/furnished
pages* as amended (together with any statement) under Article 19
pages* **10, 12** received by this Authority on **12 October 2005** with the letter of **12 October 2005**
pages* received by this Authority on with the letter of

☒ the drawings:

pages **1/5-5/5** as originally filed/furnished
pages* received by this Authority on with the letter of
pages* received by this Authority on with the letter of

☐ a sequence listing and/or any related table(s) - see Supplemental Box Relating to Sequence Listing.

3. ☐ The amendments have resulted in the cancellation of:

☐ the description, pages
☐ the claims, Nos.
☐ the drawings, sheets/figs
☐ the sequence listing (*specify*):
☐ any table(s) related to the sequence listing (*specify*):

4. ☐ This report has been established as if (some of) the amendments annexed to this report and listed below had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).

☐ the description, pages
☐ the claims, Nos.
☐ the drawings, sheets/figs
☐ the sequence listing (*specify*):
☐ any table(s) related to the sequence listing (*specify*):

* *If item 4 applies, some or all of those sheets may be marked "superseded."*

Box No. V Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	1-31	YES
	Claims	-	NO
Inventive step (IS)	Claims	1-31	YES
	Claims	-	NO
Industrial applicability (IA)	Claims	1-31	YES
	Claims	-	NO

2. Citations and explanations (Rule 70.7)

The following documents identified in the International Search Report have been considered for the purposes of this report:

D1 US 5995223 A

D2 US 6020963 A

Novelty (N)

Claims 1-31 meet the criteria set forth in PCT Article 33(2) for novelty. The prior art published before the priority date does not disclose splitting the input beam into orthogonally polarised first and second basis beams.

Inventive Step (IS)

Claims 1-31 meet the criteria set out in PCT Article 33(3) with regard to the requirement of Inventive Step because the prior art does not obviously suggest to a person skilled in the art splitting the input beam into orthogonally polarised first and second basis beams.

Industrial Applicability (IA)

The invention defined in the claims is considered to meet the requirements of Industrial Applicability under Article 33(4) of the PCT because it can be made by, or used in, industry.

cables 36 and 34 are appropriately scaled and differenced by pre-processor 27 to produce a signal corresponding to the S2 Stokes parameter on cable 40.

The S2 and S3 signals from pre-processors 27 and 37 are processed by processing module 39 to calculate $\phi = arctan(S3/S2)$ which is the phase difference imparted by piece 7. In one implementation, processing module 39 includes a suitably programmed fast digital processor and associated analog-to-digital converters to calculate the arctangent function. The processing module may also control a digital display 43, by means of cable 41, in order to generate a visual readout of ϕ.

The S_2 and S_3 detectors may be configured to measure the temporal variation in the output, the spatial variation in the output, or both. That is, the photodetection part of the detectors may include, but are not limited to, single element detectors (for example, PIN photodiode or PMT) or spatial imaging components (for example, CCD or CMOS camera). In the latter case, the signal processing must be applied on a pixel by pixel basis.

It will be realised that embodiments of the present invention involve, decomposing the output beam 12 into a pair of analysis beams that are analysed in bases different to that used to construct the input. Each component in the new bases can be expressed as a linear superposition of components of the original basis, beams 6 and 8, with a known relationship between them. Thus this relationship may be used to extract the relative phase shift between the reference and probe arms. This is then, exactly, the phase shift imparted to electromagnetic radiation by the physical system under study. Those skilled in the art will appreciate that equivalent behaviour can be realised with any two orthogonal modes, e.g. orthogonal transverse spatial modes of the field, and a phase extracted from them by an appropriate homologue of the Stokes parameters (see for example N. K. Langford et al., Physical Review Letters vol. 93, 053601 (2004), the contents of which is hereby incorporated in its entirety by cross-reference).

An embodiment of the invention which makes use of orthogonal spatial modes is depicted in use in Figure 5. With reference to that Figure, beam 45 from laser 3 is incident on a beam splitter 47 which splits the beam into beams 49 and 57. Beam 49 is incident on hologram 51 which converts beam 49 into a different transverse spatial mode beam 53. Beam 53 then passes through test piece 7 which imparts a phase

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SUMMARY OF THE INVENTION

According to a first aspect of the present invention there is provided an interferometer including:

a beam displacing assembly arranged to split an input beam into orthogonally-polarised first and second basis beams and to combine said basis beams to produce at least one output beam; and

a phase analyser arranged to analyse the at least one output beam in two polarisation bases that are superpositions of the first and second basis beams and arranged to determine a difference in phase shift imparted to one of said basis beams relative to the other by a test piece.

In one embodiment the beam displacing assembly includes first and second polarising beam displacers.

The second polarising beam displacer may be orientated inversely relative to the first polarising beam displacer.

Preferably a half-wave plate is located between the first and second polarising beam displacers.

The phase analyser may comprise a polarimetric phase retrieval assembly arranged to calculate the phase shift on the basis of signals representing Stokes parameters associated with the output beam.

In one embodiment the beam displacing assembly is arranged to impart horizontal and vertical polarizations to the first and second basis beams.

Preferably the phase analyser comprises a polarimetric phase retrieval assembly including half-wave and quarter wave plates to transform left and right circular components of the at least one output beam into corresponding vertical and horizontal components.

Preferably the interferometer includes means to discriminate between the vertical and horizontal components.

In a preferred embodiment photodetectors are included to produce electrical signals corresponding to the vertical and horizontal components.

The interferometer may include means to combine the electrical signals to produce signals corresponding to Stokes parameters.

Preferably a processor is provided that is responsive to the signals corresponding to the Stokes parameters and arranged to generate a signal indicating a phase shift imparted to one of the basis beams relative to the other.

The beam displacing assembly may include a beam splitter arranged to split the input beam into the separated first and second basis beams

In one embodiment the interferometer includes first and second holographic plates arranged to impart respectively orthogonal spatial modes to said first and second basis beams.

Preferably the interferometer includes a means to superpose the first and second basis beams thereby creating said at least one output beam.

The means to superpose the first and second basis beams may comprise a beamsplitter.

Alternatively, the means to superpose the first and second basis beams may comprise a holographic plate.

In one embodiment the means to superpose the first and second basis beams produces first and second output beams comprising a superposition of transverse spatial modes.

In one embodiment the phase analyser includes a number of spatial mode analysers each including a means to convert a desired one of said transverse spatial modes to a lowest order spatial mode.

Preferably the means to convert one of said transverse spatial modes to a lowest order spatial mode comprises a holographic plate.

Preferably the spatial mode analysers each include a spatial mode filter arranged to filter light from the holographic plate.

The spatial mode filter may comprise a single mode optical fibre.

Preferably light from said optical fibre is converted to a corresponding electrical signal by means of a photodetector.

It is desirable that the interferometer include means to combine corresponding electrical signals from each of the number of spatial mode analysers in order to obtain signals representing Stokes parameters.

Preferably a processor is provided that is arranged to process the signals representing Stokes parameters in order to generate a signal corresponding to a phase shift imparted to one of said basis beams relative to the other.

According to a further aspect of the present invention, there is provided an interferometer including:

means for splitting an input beam into an orthogonally-polarised first pair of basis beams;

means for recombining said first pair of basis beams to form at least one output beam; and

means for processing the at least one output beam in two polarisation bases that are superpositions of the first pair of basis beams to determine a relative phase shift imparted between the first pair of basis beams.

The means for splitting the input beam may be arranged so that the first pair of basis beams comprises respective orthogonally polarized beams.

More particularly, the means for splitting the input beam may be arranged so that the first pair of basis beams comprises respective horizontally and vertically polarized beams.

Preferably the means for processing the at least one output beam comprises a polarimetric phase retrieval assembly.

Alternatively, the means for splitting the input beam is arranged so that the first pair of basis beams comprises respective orthogonal spatial mode beams. In that case the means for processing the at least one output beams may include a number of spatial mode filters

The polarimetric phase retrieval assembly will preferably be arranged to calculate the phase shift from signals representing Stokes parameters.

Further preferred features of the present invention will be described in the following detailed description of exemplary embodiments wherein reference will be made to a number of figures as follows.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of an interferometer according to a preferred embodiment of the invention.

Figure 2 is a block diagram of an interferometer according to a further embodiment of the invention.

Figure 3 is a block diagram of an interferometer according to another embodiment of the invention.

Figure 4 is a block diagram of polarimetric phase retrieval module according to a preferred embodiment of the invention.

Figure 5 is a block diagram of an interferometer according to a further embodiment of the invention.

Figure 6 is a block diagram of a spatial mode analyser used in the interferometer of Figure 5.

Claims:

1. An interferometer including:

a beam displacing assembly arranged to split an input beam into orthogonally-polarised first and second basis beams and to combine said basis beams to produce at least one output beam; and

a phase analyser arranged to analyse the at least one output beam in two polarisation bases that are superpositions of the first and second basis beams and arranged to determine a difference in phase shift imparted to one of said basis beams relative to the other by a test piece.

2. An interferometer according to claim 1, wherein the beam displacing assembly includes first and second polarising beam displacers.

3. An interferometer according to claim 2, wherein the second polarising beam displacer is orientated inversely relative to the first polarising beam displacer.

4. An interferometer according to claim 2, wherein a half-wave plate is located between the first and second polarising beam displacers.

5. An interferometer according to claim 1 wherein the phase analyser comprises a polarimetric phase retrieval assembly arranged to calculate the phase shift on the basis of signals representing Stokes parameters associated with the output beam.

6. An interferometer according to claim 1, wherein the beam displacing assembly is arranged to impart horizontal and vertical polarizations to the first and second basis beams.

7. An interferometer according to claim 6, wherein the phase analyser comprises a polarimetric phase retrieval assembly including half-wave and quarter wave plates to transform left and right circular components of the at least one output beam into corresponding vertical and horizontal components.

8. An interferometer according to claim 7, including means to discriminate between the vertical and horizontal components.

18. An interferometer according to claim 17, wherein the phase analyser includes a number of spatial mode analysers each including a means to convert a desired one of said transverse spatial modes to a lowest order spatial mode.

19. An interferometer according to claim 18, wherein the means to convert one of said transverse spatial modes to a lowest order spatial mode comprises a holographic plate.

20. An interferometer according to claim 19, including a spatial mode filter arranged to filter light from the holographic plate.

21. An interferometer according to claim 20, wherein the spatial mode filter comprises a single mode optical fibre.

22. An interferometer according to claim 21, wherein light from said optical fibre is converted to a corresponding electrical signal by means of a photodetector.

23. An interferometer according to claim 22, including a means to combine corresponding electrical signals from each of the number of spatial mode analysers in order to obtain signals representing Stokes parameters.

24. An interferometer according to claim 23, including a processor arranged to process the signals representing Stokes parameters in order to generate a signal corresponding to a phase shift imparted to one of said basis beams relative to the other.

25. An interferometer including:

means for splitting an input beam into an orthogonally-polarised first pair of basis beams;

means for recombining said first pair of basis beams to form at least one output beam; and

means for processing the at least one output beam in two polarisation bases that are superpositions of the first pair of basis beams to determine a relative phase shift imparted between the first pair of basis beams.